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PRELIMINARY GEOLOGIC EVALUATION OF L-BAND

RADAR IMAGERY - ARKANSAS TEST SITE

FINAL REPORT

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ABSTRACT

Radar imagery at 25 cm wavelength (L-band) was obtained over the Arkansas test site on November 4, 1976 and May 29, 1977. Preliminary geologic evaluation of the Jet Propulsion Lab L-band data included comparison with Landsat, Skylab, and other shorter wavelength radar imagery previously obtained over the test site.

The relatively small angles of incidence (steep depression angles) of the L-band system provide minimal shadowing on terrain back-slopes and considerable foreshortening on terrain fore-slopes which sacrifice much of the topographic enhancement afforded by a more oblique angle of illumination. In addition, the dynamic range of the return from vegetated surfaces is substantially less for the L-band system, and many surface features defined primarily by subtle changes in vegetation are lost. In areas having terrain conditions similar to those of northern Arkansas, and where Landsat and shorter wavelength aircraft radar data are available, the value of the JPL L-band imagery (especially in the normal mode configuration as mounted in the NASA Convair 990) as either a complimentary or supplementary geologic data source is not obvious. If the L-band imagery provided for this preliminary evaluation is an example of what might be expected from space (SIR-A), then we anticipate a considerable degree of reluctance by the geologic community to accept radar as an improved geologic remote sensing technique.

New Technology None

OBJECTIVE

The Landsat and Skylab programs have demonstrated conclusively the utility of spacecraft data for mineral and petroleum exploration. Though short wavelength imaging radars have been used successfully for geologic mapping throughout the world, the exploration significance of longer wavelength SLAR systems has not been evaluated. The short term objective of this research program was to provide a preliminary evaluation of L-band radar imagery for geologic interpretation and mapping in an area having contrasting terrain types and geologic structure. West-central Arkansas provides an ideal test site for imagery comparisons in a relatively heavily forested area. Data comparisons were to include Landsat and Skylab imagery, and other radar imagery where available.

The ultimate objective of future analyses (when sufficient radar imagery for the Arkansas test site becomes available) will be to demonstrate the utility of temporal multifrequency-polarization radar data for mineral and petroleum exploration. Radar parameters to be evaluated eventually include viewing angle, vegetation penetration, multifrequency-polarization, temporal aspect, effect of snow cover, and the compatibility of a Landsat-radar merge.

LOCATION

Background Parts of two major physiographic regions of the southern United States are within the boundaries of Arkansas, the Gulf Coastal Plain which covers the southern and eastern sections of the state and

the Interior Highlands encompassing the northern and western parts (Fig. 1). Physiographically Arkansas is divided into two nearly equal areas, the highlands in the northwestern half and the lowlands in the southeastern half. The Interior Highlands can be subdivided into Ozark Plateaus and Ouachita Mountains provinces. The Ouachita Mountains province consists of two subdivisions, the Arkansas Valley and Ouachita Mountains.

The Ozark Plateaus province covers northern Arkansas and consists of three well-defined steplike surfaces, the Salem Plateau, Springfield Plateau, and Boston Mountains. Rock types in the plateaus are sedimentary and the units are relatively undeformed. The Salem Plateau is characterized mainly by elevation of 150 to 300 meters above sea level. Streams are gradually dissecting the broad uplands and the area is undulating to hilly, relief generally not exceeding 60 meters. In the Springfield Plateau elevation generally ranges from 300 to 450 meters. The Boston Mountains are the higher southern edge of the Ozarks. The mountains are primarily flat-topped summit ridges representing the original erosion surface of the plateaus. Severe stream dissection has created steep-sided mountains and deep narrow valleys. Elevation generally ranges from 450 to 680 meters but in places exceeds 750 meters. Relief is mainly within the 150-300 meter range but in places exceeds 500 meters. The northern boundary is well marked by a retreating escarpment in most areas. On the south, the mountains descend rather abruptly to the Arkansas Valley region.

The Ouachita Mountains in the west-central part of the state also are composed of sedimentary rocks, but they have been folded into

ARKANSAS PHYSIOGRAPHIC REGIONS

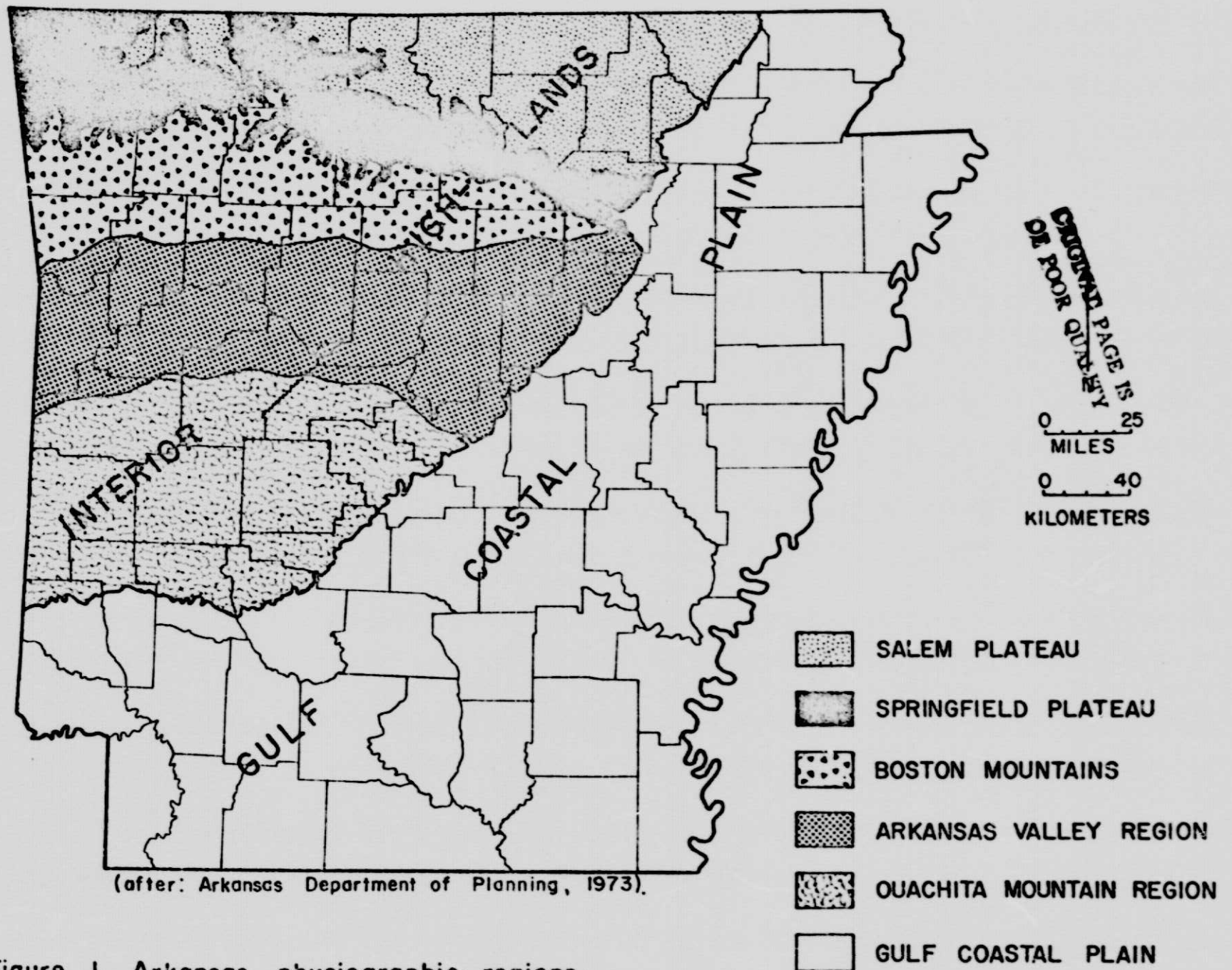


Figure 1. Arkansas physiographic regions

generally parallel ridges and valleys in an east-west orientation. Most of the mountain ridges are narrow with steep slopes; crests tend to be sharp; valleys are generally rather broad. Within the Ouachita Mountains province, subdivisions are distinguished mainly by the spacing of the folds. The Arkansas Valley region, for example, is from 45 to 65 kilometers wide and is characterized by widely spaced ridges straddling the Arkansas River which flows from northwest to southeast.

Test Site Specifics The Arkansas test site provides an ideal region for a geologic evaluation of multifrequency SLAR systems. Vegetation cover ranges from agricultural crops and pasture to ground-masking deciduous, coniferous, and mixed forest types.

Geologically, the Arkansas test site is within the Arkoma basin, an east-trending structural trough (synclinerium) extending across Arkansas and into Oklahoma (Fig. 2). In Oklahoma this basin is occasionally referred to as the McAlester basin, whereas the Arkansas part is called the Arkansas Valley, which essentially includes all of the Arkansas test site. The northern flank of the Arkansas Valley is characterized by gently folded sedimentary rocks. On the south is a medial zone of moderate folding. The southern limit of the Arkansas Valley consists of a zone of very intense folding which has been further modified by shear and thrust faulting because of proximity to the northern Ouachita Mountains.

The Arkansas Valley part of the Arkoma basin is largely responsible for Arkansas' ranking as the eighth leading gas-producing state in the United States. The main production is within a 50 km swath that crosses parts of 10 counties (Fig. 3).

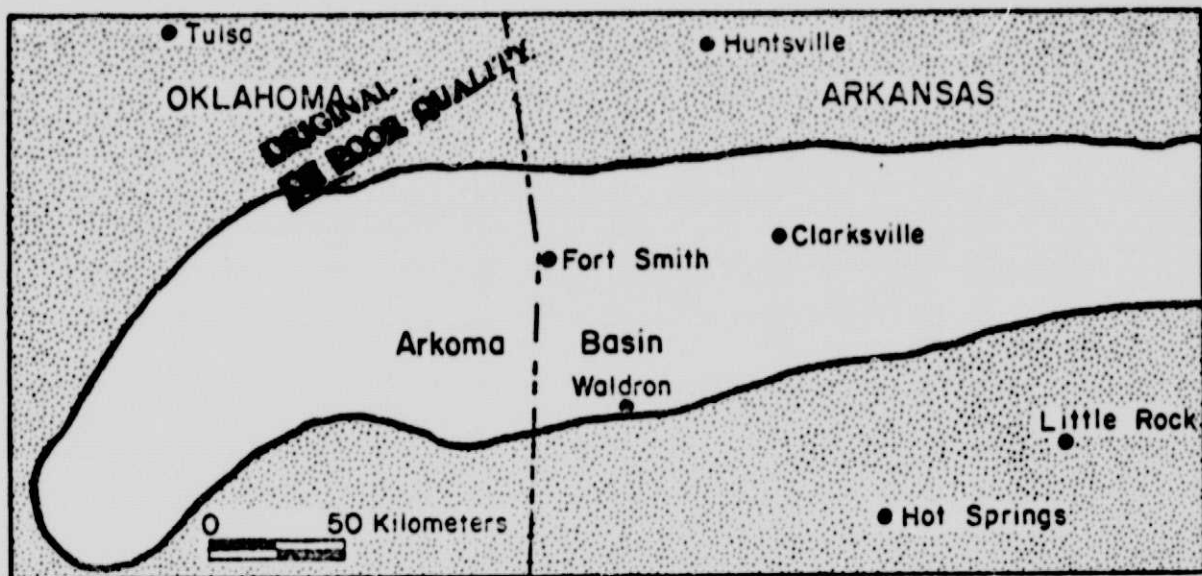
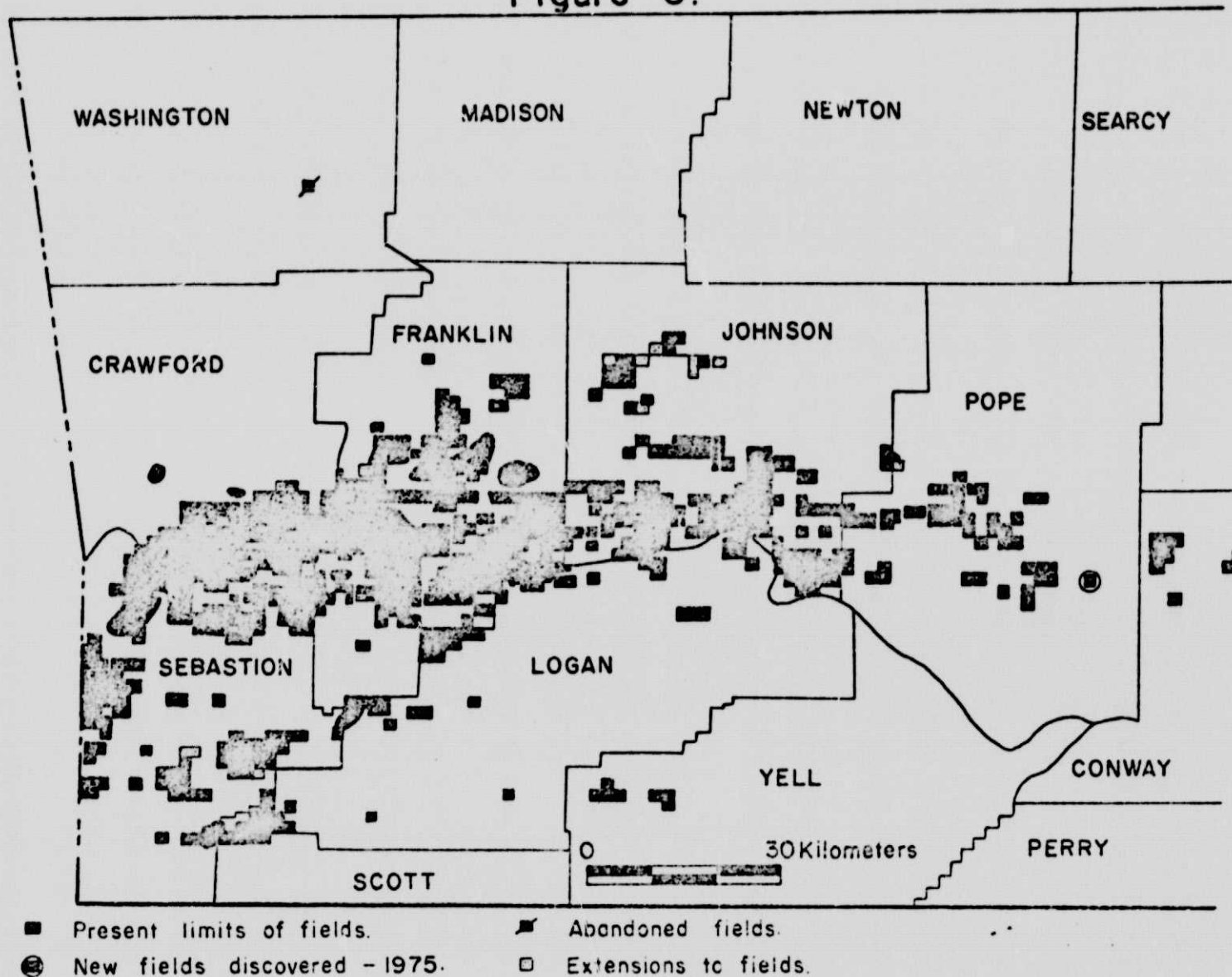


Figure 2.

Figure 3.



Test Site Radar Coverage Radar imagery at 25cm wavelength (L-band) was obtained over the Arkansas test site on November 4, 1976 and May 29, 1977. The November data consisted of a single east to west swath (14 km wide) across the test site, whereas the May coverage provided 10 north-south flight lines covering approximately 23 km for each swath width and 100 km for each flight line length. The November flight had a single polarization configuration (HH), whereas the May flight provided dual-polarization, HH, and HV. The SLAR geometry for the L-band data is shown in Figure 4.

RADAR INTERPRETATION

The task of the interpreter using radar imagery for geologic analysis includes the identification of faults, folds, and diagnostic landforms which have been faithfully reproduced in the radar image format. In addition, radar imagery interpretation, like photogeology, is an attempt to define geologic subsurface conditions, which can be inferred through the analysis of stream patterns, soil textures and patterns, lineations, the shapes of hills and valleys, and the presence or absence of specific types of vegetation. Some geologic features are so clearly expressed in their landform configuration that they can be identified directly; the nature of others can be determined only by ground examination. The extent to which geology can be mapped from radar terrain data varies considerable and depends on the terrain environment and the terrain format provided on the imagery. The terrain environment, or the geologic and geomorphic characteristics of a region, depends primarily on the climate and density of vegetation, surface expression

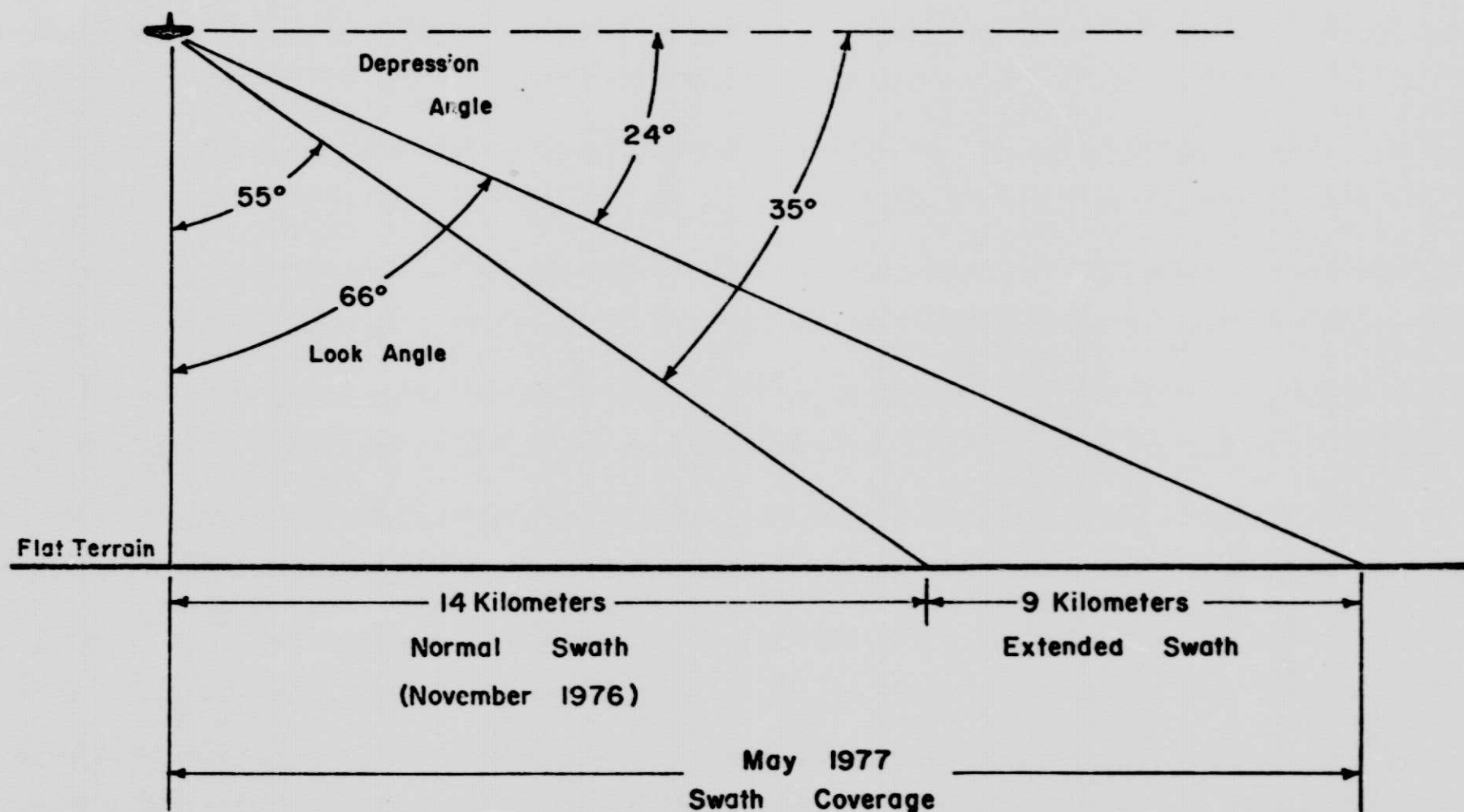


Figure 4. L-band SLAR geometry

of landforms, and amount of surficial debris. The terrain format, however is provided by the radar imagery and is usually directly related to microwave system characteristics in general, as well as certain specific operational system parameters. Imagery format, radar foreshortening, and radar shadowing are of particular concern in evaluating the L-band SLAR system for geologic interpretation.

Imagery Format Radar imagery usually is presented on recording film in either slant range or ground range presentation. Slant range sweeps are linear, so the spacing between return signals on the image is directly proportional to the time interval between the terrain features being recorded. For ground range sweeps, the spacing is modified to equate the image scale to that which the terrain features would actually have on the ground if the latter were both flat and at a fixed altitude beneath the aircraft. Because return signals are recorded on slant range imagery displays with a spatial separation directly proportional to the time interval between them, near range distances will be relatively compressed whereas far range distances will more nearly approximate the ground distances. The L-band SLAR imagery was recorded as a slant range display. In the far range of the extended swath (Fig. 4) equidistant adjacent points vary only slightly from their true planimetric positions; however, in the near range large changes in scale occur. Near range compression and contrasting scale changes on opposite sides of a swath make mosaicking of adjacent flight lines almost impossible. Of considerable importance to the geologist is the fact that geologic interpretation of the near range part of the present L-band imagery format is essentially impossible. For example, similar

terrain points on Figure 5 can be compared with those of Figure 6. Near range compression on Figure 6 is so severe that terrain features 1-6 are almost unrecognizable. Because of this distortion, approximately 20 percent of the image provides little useful geologic information.

Radar Foreshortening A characteristic of all radars imaging irregular terrain surfaces, the variation in the length of equal terrain slopes when the slope measurements are taken at different incidence angles, is known as radar foreshortening. For example, in Figure 7 the fore- (toward radar) and back- (away from radar) slope lengths of terrain features 1, 2, 3, and 4 are equal; however, the same slope lengths as they are seen and recorded on the radar imagery vary considerably over the total range of incidence angles. More simply, the length of a terrain slope on imagery is dependent on the time it is illuminated. The fore-slope length of terrain feature 2, recorded on the imagery, is less than half of the back-slope length because the radar illuminates the back-slope almost twice as long as the fore-slope. The same fore-slope length on terrain feature 3 is imaged as a single line when the top, middle, and bottom of the slope are "seen" at the same time. Where the incidence angle approaches vertical incidence as it has on terrain feature 3, radar foreshortening is maximum, but where the incidence angle approaches grazing (largest incidence angles, such as the far range of Fig. 7) the effects of foreshortening are minimal. Only at grazing are terrain slopes seen in their true length. The relationship between incidence angle and the amount of foreshortening is shown in Table I.

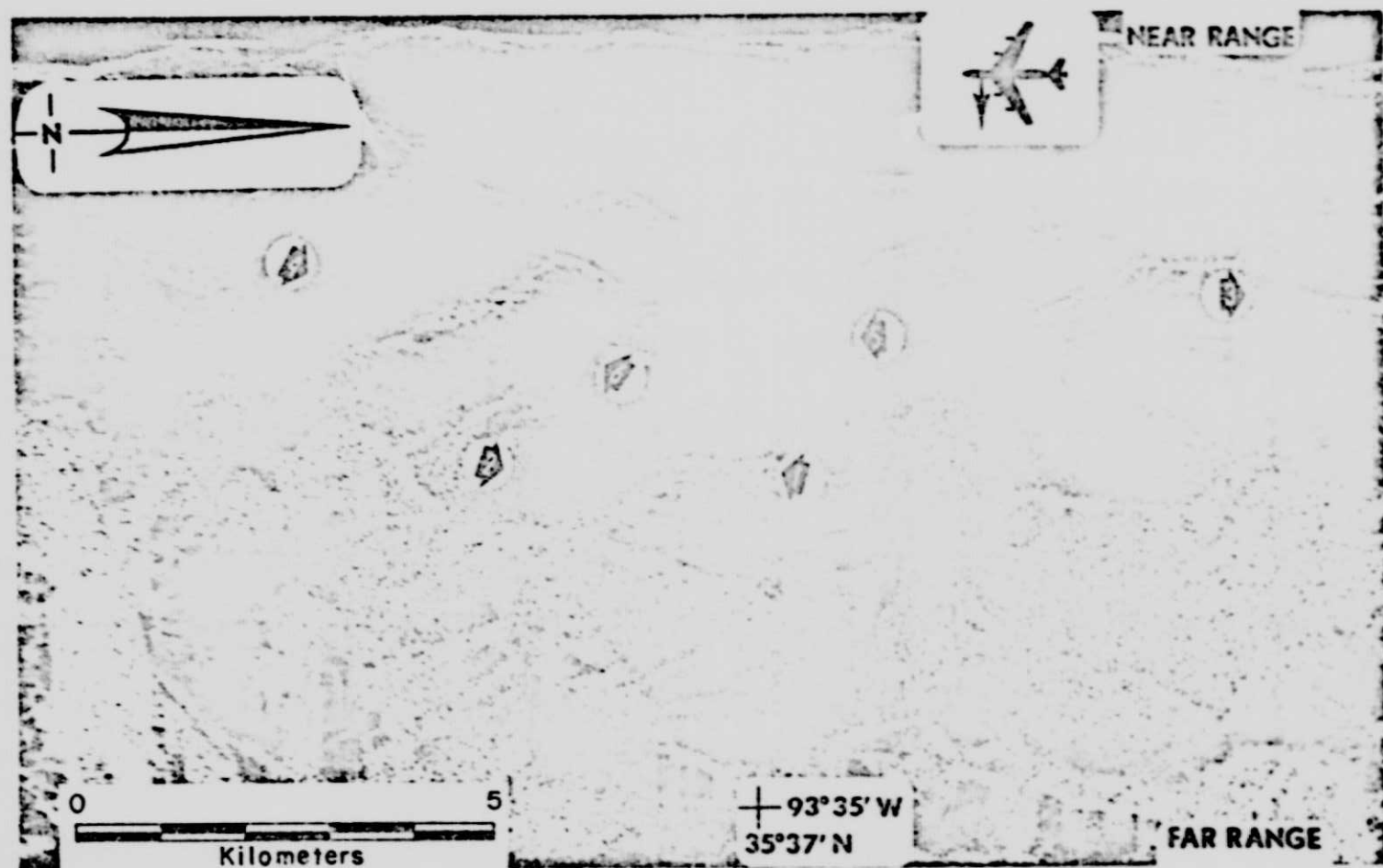


Figure 5. L-band radar imagery

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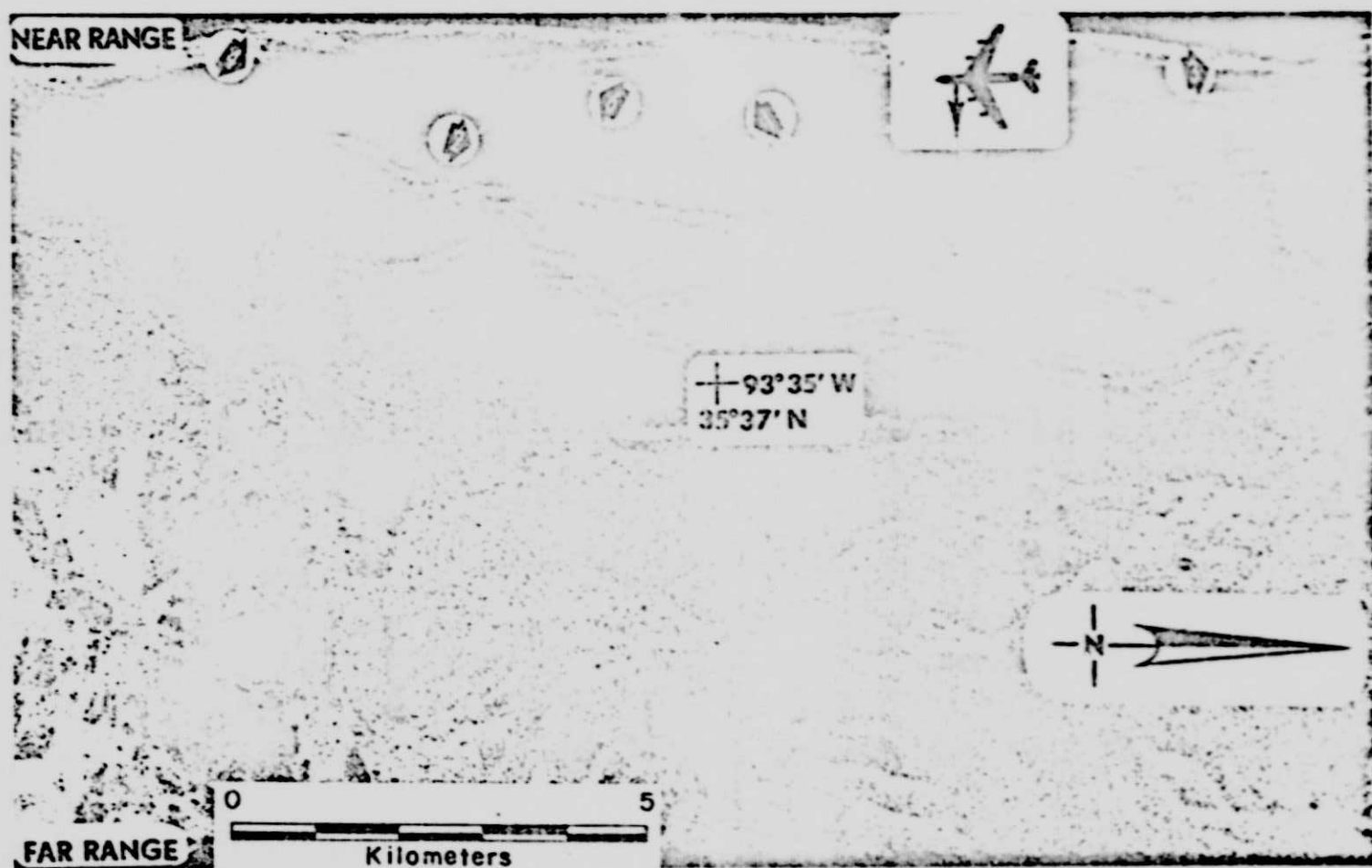


Figure 6. L-band radar imagery

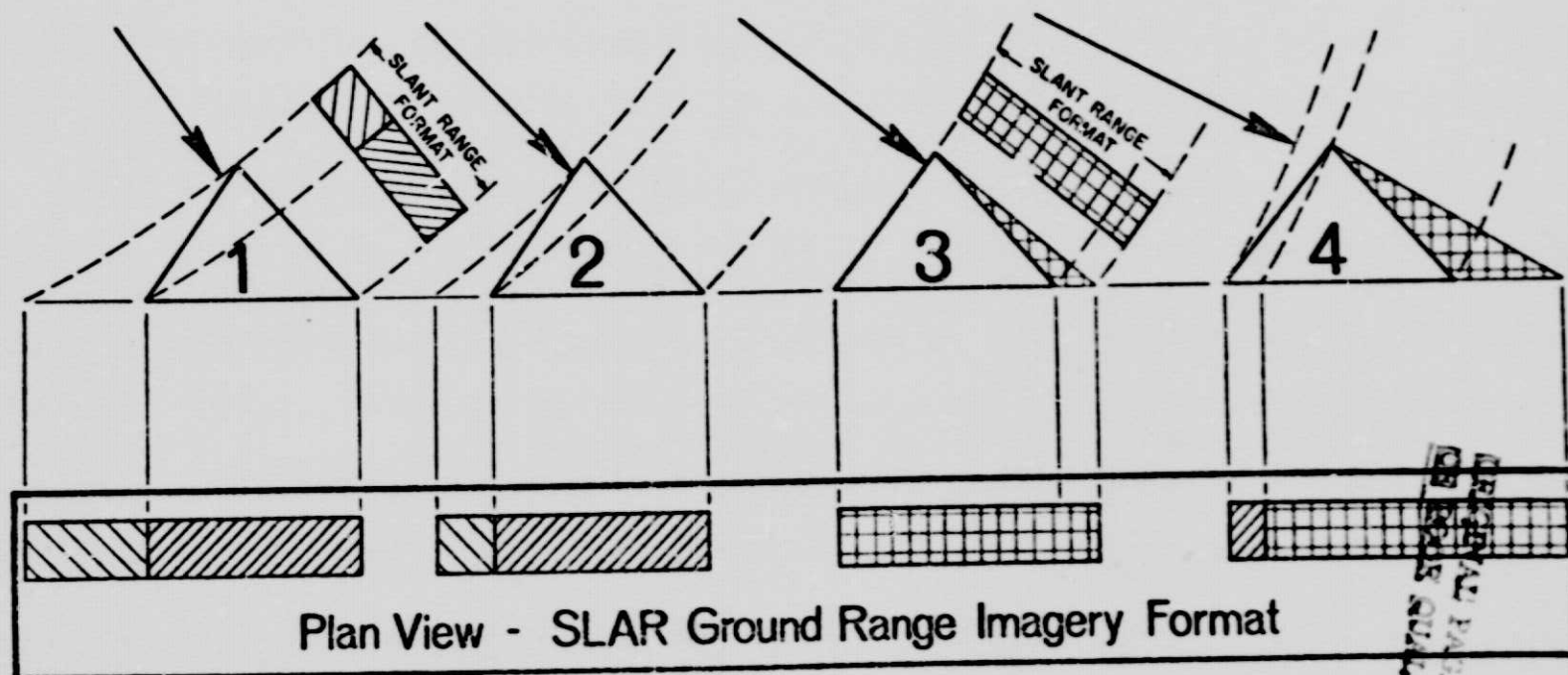
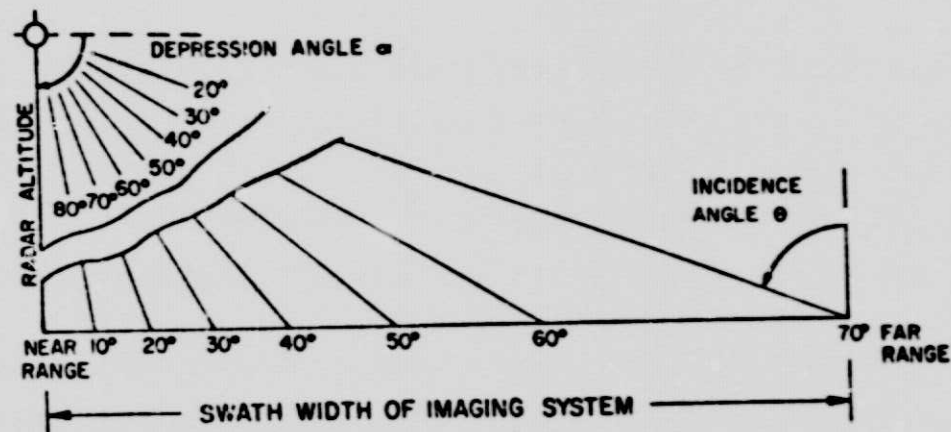
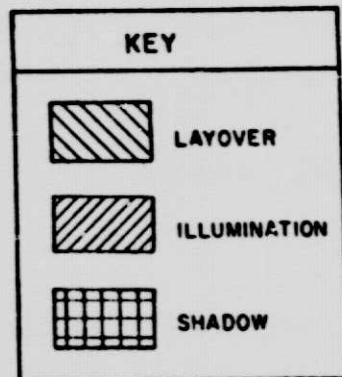


Figure 7.

TABLE I

Incidence Angle	Percent Radar Foreshortening
90 (Grazing)	0.0
80	1.5
70	6.0
60	13.4
50	23.4
40	35.7
30	50.0
20	65.8
10	82.6
0 (Normal Incidence)	100.0

Radar Layover Wherever terrain fore-slope exceeds the complement of the depression angle, radar layover will occur. In Figure 7, the top of terrain feature 1 is recorded on the imagery prior to the base because the slant range distance from transmitter to the top of feature 1 is less than the slant range distance to the base. For terrain feature 3, the top and base are imaged as a single line; in this case, terrain slope (50°) and complement of depression angle are equal (normal incidence, Table I). Terrain feature 4 is imaged normally, i.e., with the base portrayed closer to the nadir of the aircraft, because the slant range distance to the base of feature 4 is less than the slant range distance to the top. Obviously, the effect of radar layover is most pronounced for large depression angles and steeply sloping terrain elements; however, with the extremely steep depression angles in the normal L-band swath (Fig. 4), even slopes of a mere 20

degrees will be in layover in the near range. Compare, for example, the terrain fore-slopes at feature 1 on Figures 5 and 6. The combined effect of radar foreshortening and layover is clearly illustrated by comparing Figures 5 and 6 in the area between terrain point 2 and the latitude ($35^{\circ}37' \text{ N}$)--longitude ($93^{\circ}35' \text{ W}$) tick mark intersections.

Radar Shadow Shadows on aerial photographs are a function of the positions of both the camera and the sun. Radar provides its own "illumination" and radar shadows are always present whenever terrain back-slope exceeds depression angle. The shadowing of terrain features (of equal relative relief) being viewed from near to far range will increase as depression angle decreases (Fig. 7). Thus it is possible to image relatively homogeneous topography with SLAR imaging systems and have equivalent slopes along the swath width fully "illuminated" in the near range but in partial or complete shadow in the far range.

Because radar images the terrain at comparatively low incidence angles, the shadows formed on the imagery are analogous to shadows formed on aerial photographs taken at low sun angle. This oblique shadowing has aided in defining topographically expressed geologic features on photographic, Landsat, and radar imagery. Thus, in low relief areas, shadowing is desired for the geologic interpretation. To illustrate the effect of varying depression or incidence angles on terrain interpretation, Figure 8 provides an example of terrain illumination at different angles of incidence or look angles. At relatively large incidence angles of 30° to 60° (depression angles of 10° - 30°), subtle terrain texture becomes enhanced by shadowing, whereas at smaller incidence angles (steeper

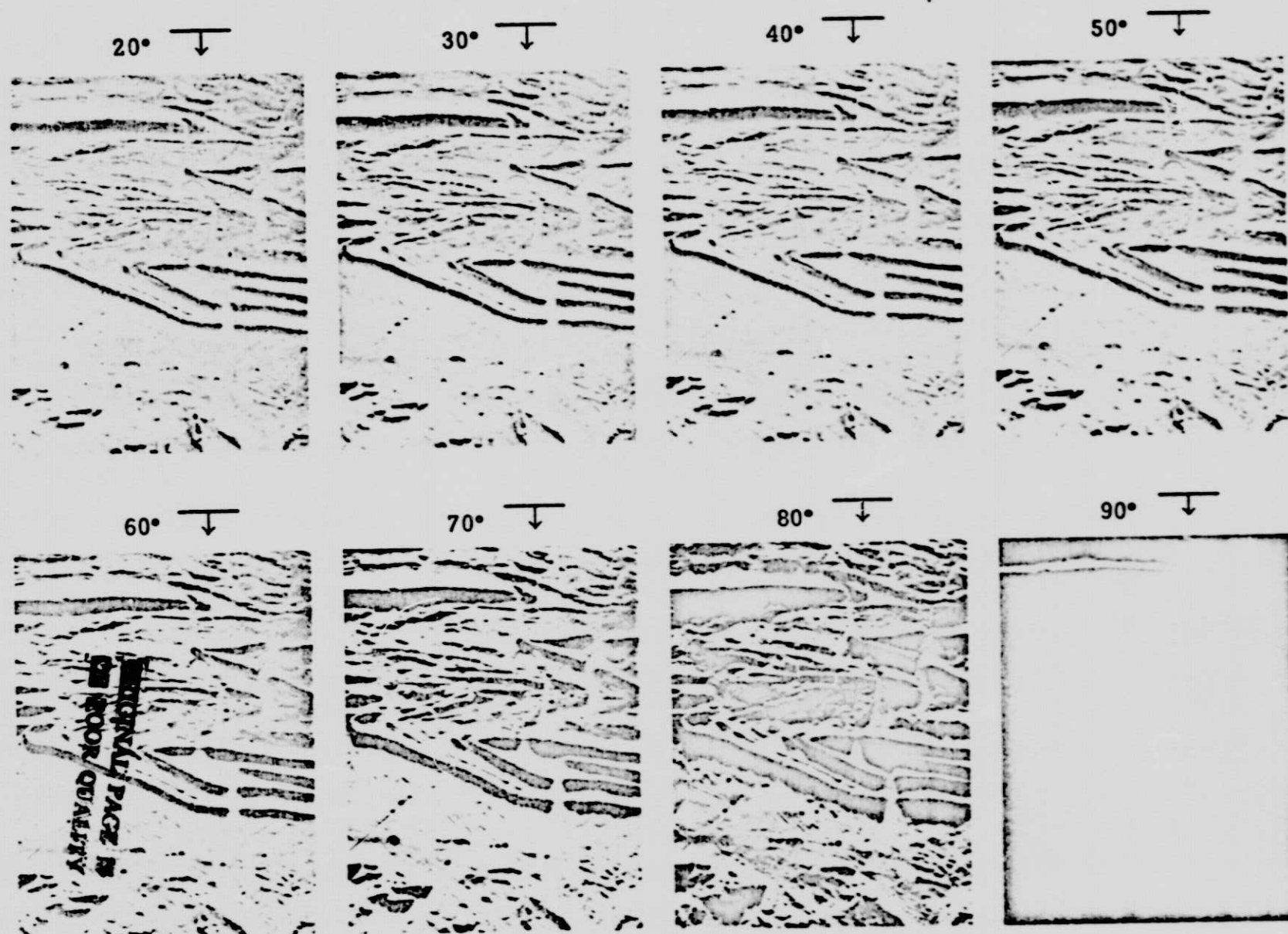


Figure 8. Plaster terrain model illuminated at various incidence angles

depression angles) many terrain discontinuities become less obvious.

Radar Comparison The relatively small angles of incidence (steep depression angles) across the swath width on the normal mode L-band imagery provide for minimal shadowing on terrain back-slopes and considerable foreshortening of terrain fore-slopes. Compare, for example, similar terrain features on Figures 9-12. Figure 9 is a Landsat image, Figure 10 is an X-band image (ground range), and Figures 11 and 12 provide examples of L-band data. Contrasting Figure 11 with Figures 9 and 10 shows the influence of shadowing for enhancing the landforms that is so important for geologic analysis. Terrain slopes in the region of points 1-4 average approximately 28° and relative relief is generally about 150 meters; but the lack of shadowing and consequent suppression of landform definition is evident on the L-band image.

Detection of drainage patterns other than major tributaries is especially difficult on the L-band imagery. Figures 13 and 14, which are on approximately the same scale, provide a contrast between Ka- and L-band imagery. Notice, for example, the lack of topographic detail on Figure 14 extending east from Terrain point 3. The relatively shallow depression angles of the Ka system allow for the delineation of considerable terrain information because of shadowing. Because terrain evaluation is relatively difficult on the L-band imager, geologic interpretation would be equally difficult, and such a data base would provide marginal utility for the geologist.

If terrain enhancement by shadowing is considered, operation of the JPL L-band system in the extended swath mode (Fig. 4) provides a

swath of relatively high incidence angles (shallow depression angles) that gives a better image product than the normal swath mode. The extended and normal swaths of similar terrain are illustrated in Figures 15A and 15B, respectively. The more oblique angles of illumination in the extended swath (Fig. 15A) do indeed provide an image format which allows for an improvement in overall geologic interpretability. However, when the same terrain is imaged at even more oblique angles (shallower depression angles) as in Figure 15C (far range at approximately 15° depression angle), a significant increase in extractable terrain information is noted.

The imagery comparisons illustrated in Figure 15 demonstrate and emphasize the importance of radar illumination angle for geologic interpretation when aircraft-mounted systems are used. However, if one considers the illumination angles proposed for SIR-A (swath centered at approximately 40° depression angle), then the geologic value of the imagery (in a terrain similar to that of Arkansas) becomes suspect. Most alarming is the fact that although Figure 15C provides for near optimum geologic data extraction, and Figure 15A illustrates the optimum illumination angles available with the aircraft-mounted JPL L-band system, neither of these two swaths is representative of SIR-A illumination angles. At best, SIR-A will provide shadowing similar to that in the far range of Figure 15B (35° depression angle) for terrain environments similar to the Arkansas test site. If we assume that a similar product would be obtained from space and if Landsat, photographic, and aircraft radar data are not available, then some geologic information could be extracted; however, the complementary or supplementary value in relation to other data sources is not obvious at this time.



Figure 9. Landsat image, part of Arkansas test site, solar illumination 21°

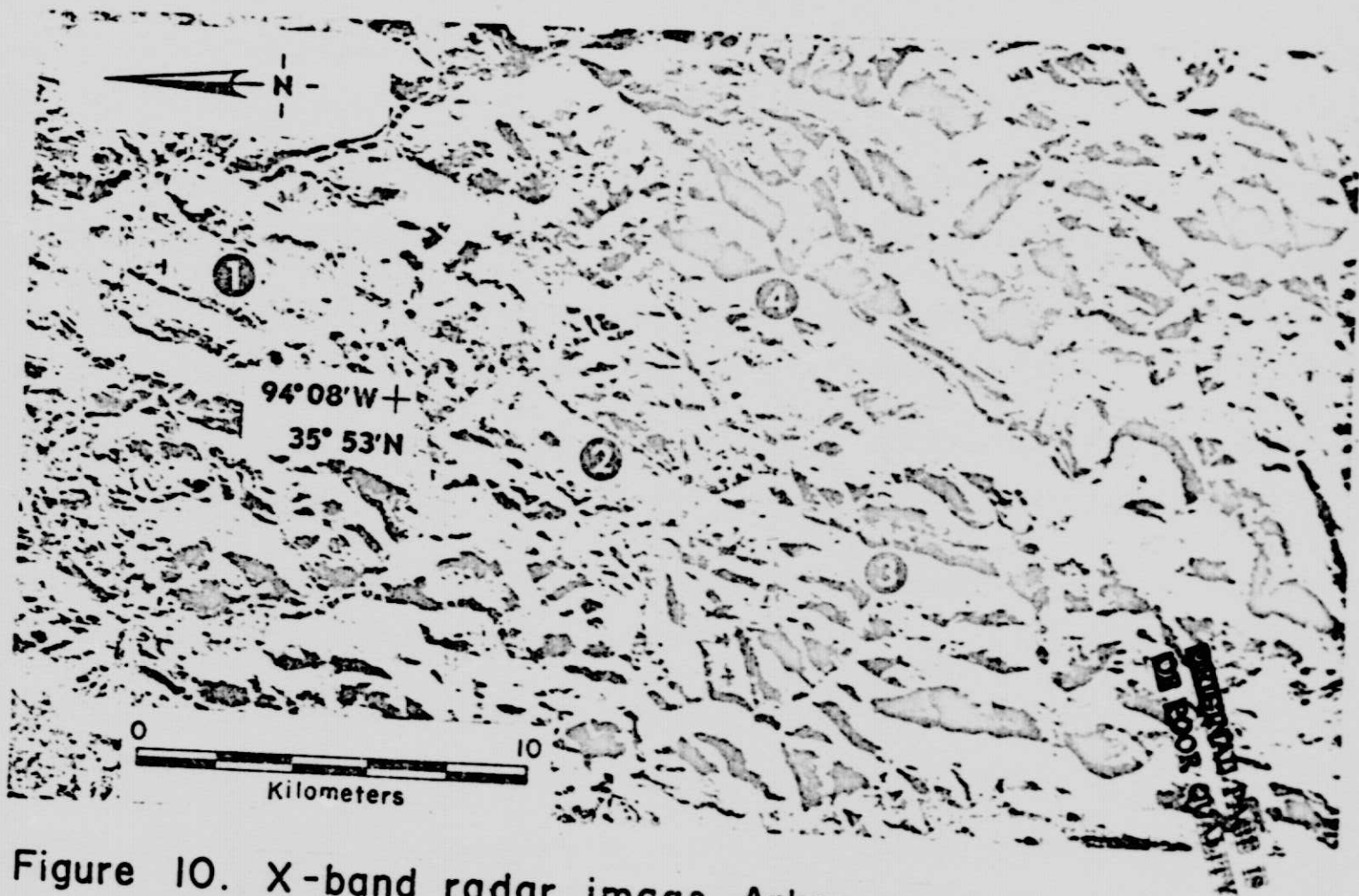


Figure 10. X-band radar image, Arkansas

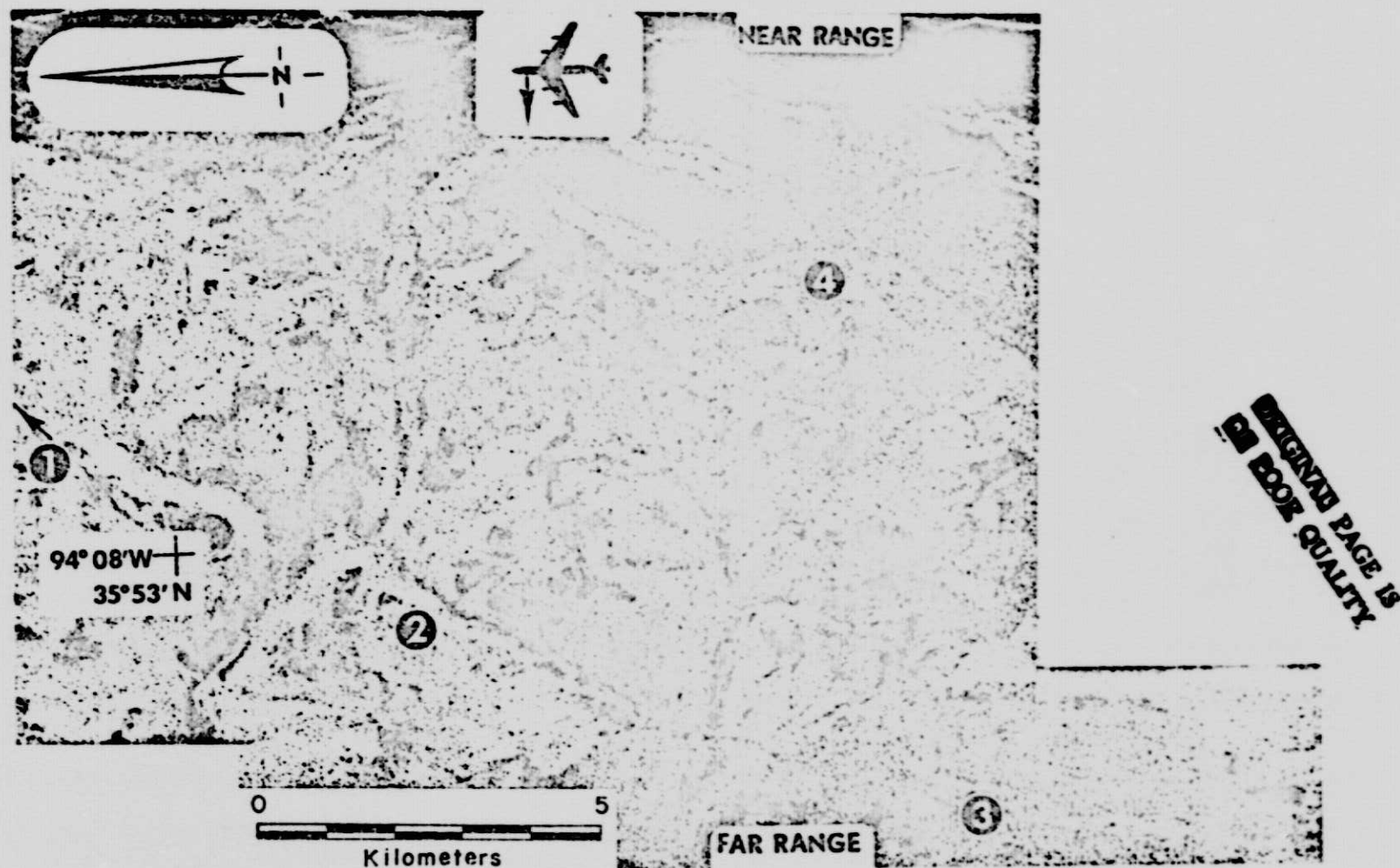


Figure II. L-band radar image , Arkansas

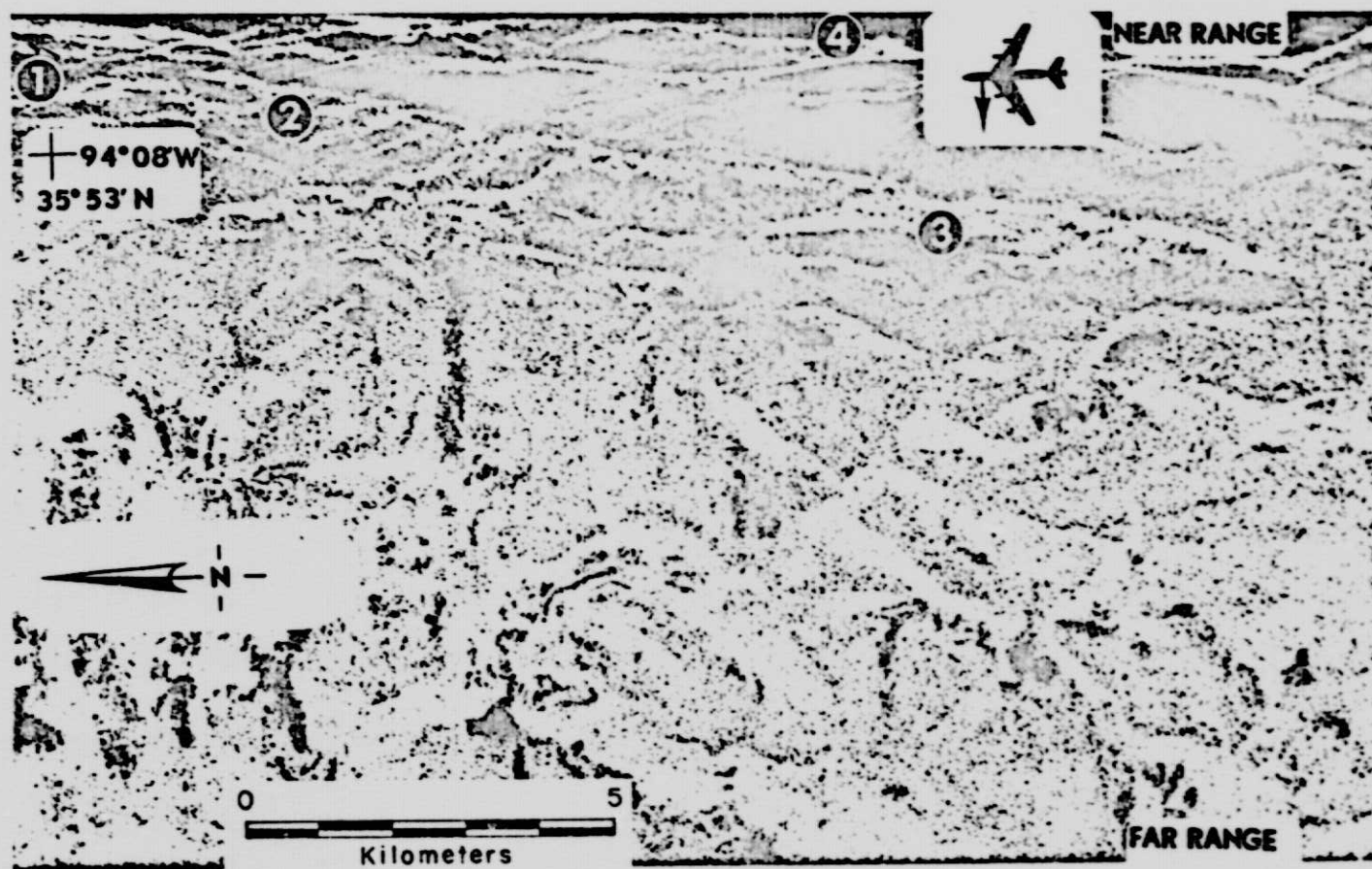


Figure 12. L-band radar image, Arkansas

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Vegetation Penetration Commercial imaging radars (currently X-band, approximately 3cm wavelength) do not have a significant terrain penetration capability. The relatively high moisture content and consequent high conductivity of vegetation, soil, and rock preclude (except in a few special cases) substantial penetration into the subsurface. Although SLAR systems have successfully provided mapping data for many of the world's most remote jungle regions, geologic interpretation was performed on imagery which basically portrayed the top of a continuous canopy of vegetation. In comparison with conventional sensors, longer wavelength systems hold promise for improving vegetation penetration and perhaps providing additional terrain information.

The L-band imagery for the Arkansas test site was obtained when the trees were in full leaf. Figure 13 shows Ka-band imagery obtained in July of 1966 and, although any comparison with L-band (1976-77) is poor because of the 10-year interval, general forest types are still the same. Figure 14 illustrates the forest patterns on the L-band. Cleared areas on the L-band (area 3 for example) show black and forested areas show gray. The dynamic range of the return from vegetation surfaces appears to be substantially less for the L-band system, and many surface features defined primarily by subtle changes in vegetation are lost. This loss is not unexpected because at L-band wavelengths the sensitivity to roughness scales on the order of leaf size should be less. In addition, a significant amount of penetration of leafy matter probably occurs and the resulting roughness comes from a combination of branches, trunks, and even the ground below. It is possible that some additional discrimination of vegetation boundaries

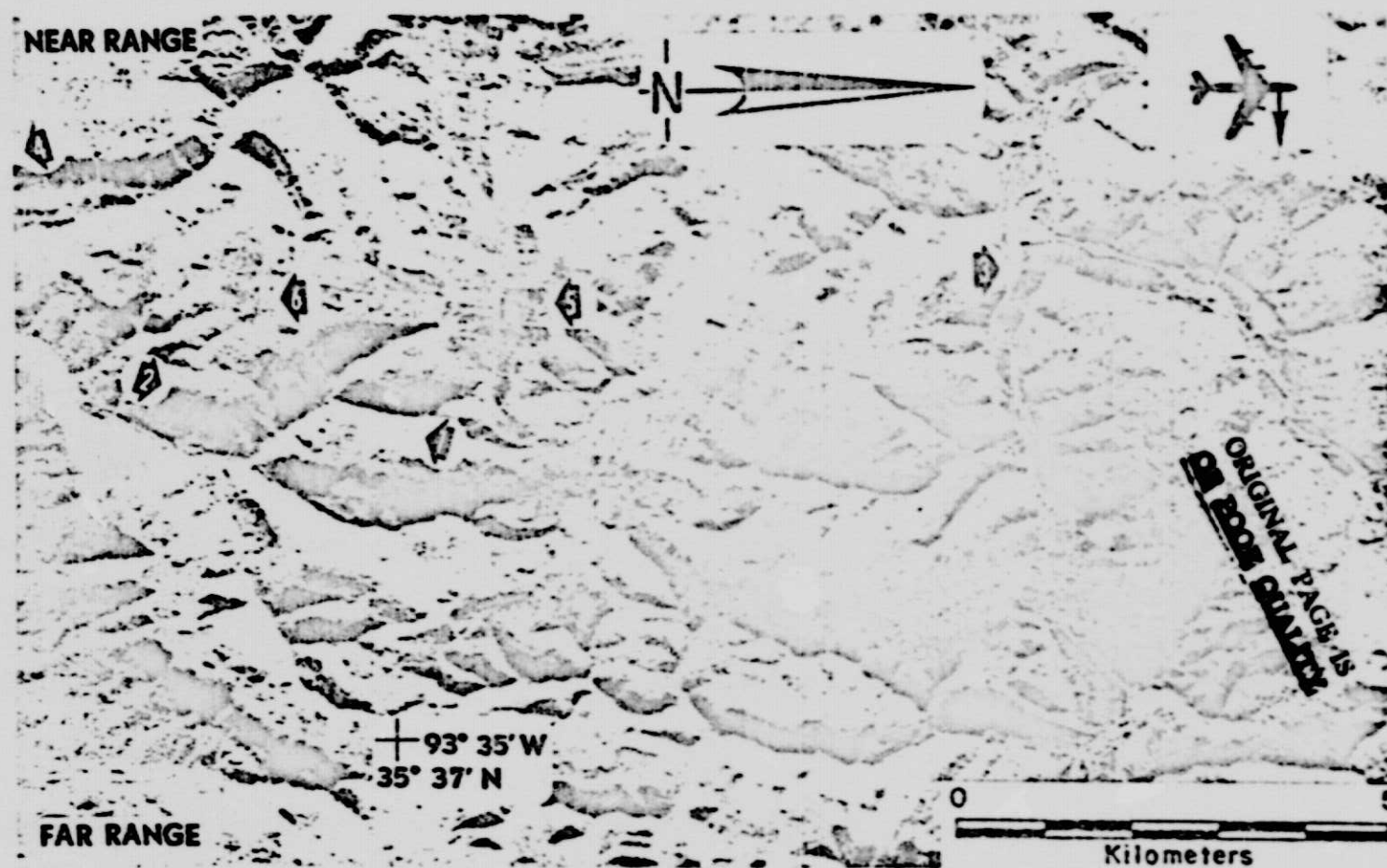
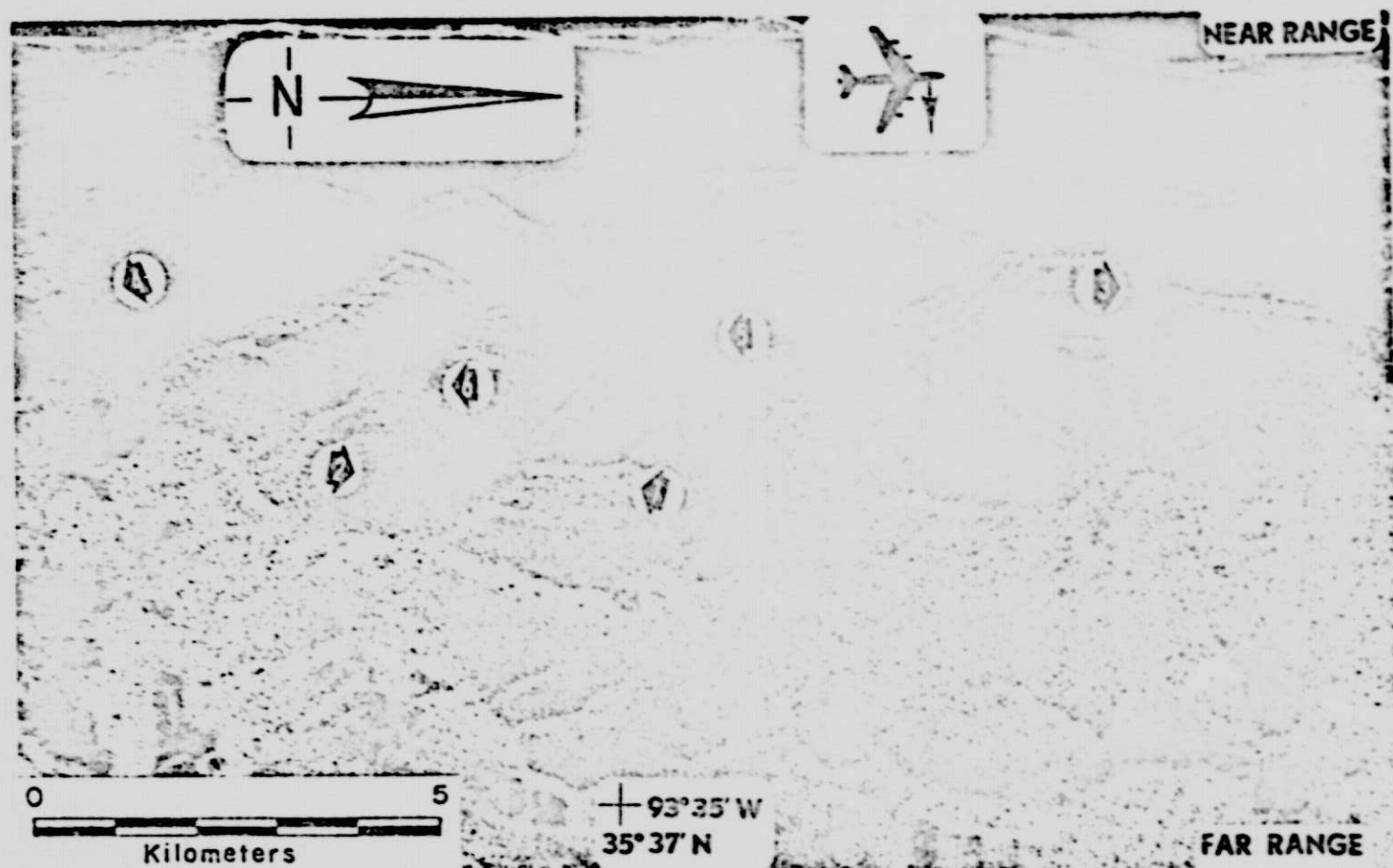


Figure 13. Ka-band radar imagery



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Figure 14. L-band radar imagery

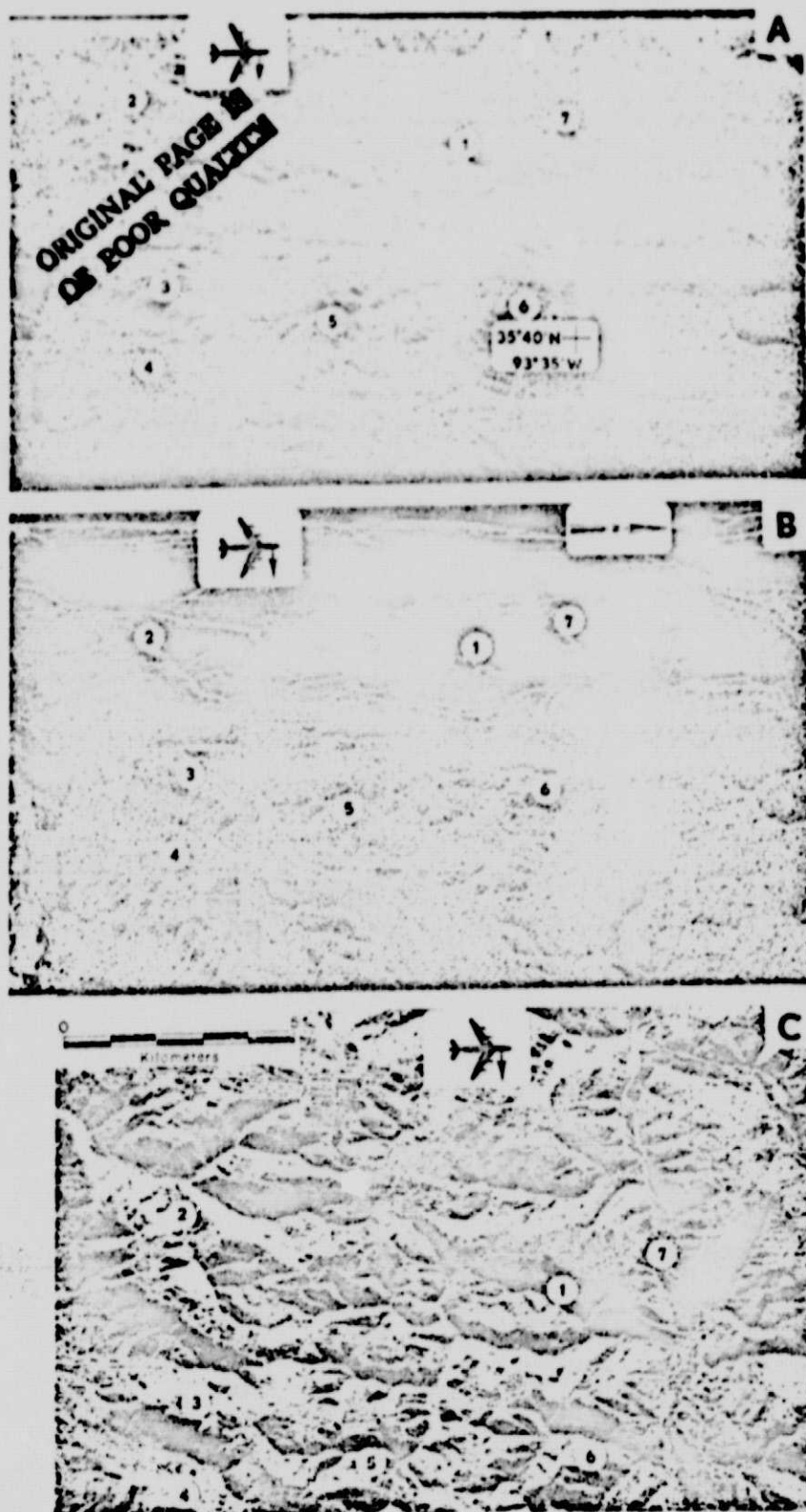


Figure 15. A-extended swath JPL, L-band; B-normal swath JPL, L-band; and C-swath of Ka-band imagery.

could be performed on those areas currently below the film threshold, and such data processing might extract surface roughness information.

Polarization Funding for this project was not sufficient to provide ground truth information for polarization analysis; however, two general observations can be made:

1. Polarization differences in the natural terrain (forested) areas were not obvious.
2. Polarization differences were observed in some agricultural areas but sensitivities appear to be related to bare fields rather than crop differences.

SUMMARY

The evaluation of differences in image quality due to changes in operational frequency is hindered by several system dissimilarities. In particular a comparison of the L-, X-, and Ka-band radar imagery is difficult because of differences in "effective" resolution. Though the physical resolution of these systems may be somewhat comparable, the inherent averaging of the real aperture systems (X- and Ka-) provides an apparent wider range of gray tones. This effect is related to the fact that at a scale where the resolution cell is discernable, the coherent scintillation of "speckle" of the synthetic aperture L-band system masks tonal variations. At a compressed scale where the observer's eye performs some averaging of resolution cells, much of the gray scale is recovered. This mismatch of effective resolution impedes detection of small changes in gray tone and makes subtle boundary changes less distinct.

The relatively steep depression angle of the L-band system sacrifices much of the topographic enhancement afforded by a more oblique angle of illumination. The combination of foreshortened fore-slopes and lack of shadowing on most back-slopes results in a considerable handicap to the geologist using the JPL L-band imagery. If the L-band imagery provided for this preliminary evaluation is an example of what might be expected from space (SIR-A), then we anticipate a considerable degree of reluctance by the geologic community to accept radar as an important geologic remote sensing technique. Especially in areas having terrain conditions similar to those of Arkansas, and where Landsat, photographic, and aircraft radar data are available, the value of the JPL L-band imagery as either a complementary or supplementary geologic data source is not obvious. Providing shallower depression angles will help improve overall geologic utility; however, the compression of gray tones will have to be addressed if a useable image is to be provided to the geologist.